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Generative AI as Pedagogical Scaffolding in Project-Based Learning: A Systematic Literature Review

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Abstract

With the rapid development of generative artificial intelligence (GenAI), its applications in education have gradually expanded beyond information retrieval and content generation to include support for the learning process. Project-based learning (PjBL) emphasizes authentic, problem-oriented learning through sustained inquiry, collaboration, and practical engagement to promote students' knowledge construction and competency development. However, the role of GenAI as pedagogical scaffolding in PjBL has not yet been systematically investigated. Following the PRISMA guidelines, this study conducted a systematic literature review of English-language, peer-reviewed journal articles published between 2023 and 2026. Following systematic searching and screening, 33 studies that met the eligibility criteria were included. The review focused on the types and functions of GenAI scaffolding, the ways in which it supports students across different phases of PjBL, and its relationships with student learning outcomes. The findings identified six types of pedagogical scaffolding provided by GenAI in PjBL: conceptual, procedural, strategic, metacognitive, collaborative, and motivational scaffolding. These forms of support reflect the diverse functions of GenAI in facilitating knowledge understanding, task implementation, learning regulation, and social interaction. Furthermore, GenAI scaffolding was found to operate across four phases of PjBL-planning, inquiry, execution, and reflection, with the execution phase receiving the greatest research attention. Finally, GenAI scaffolding was positively associated with students' academic achievement and cognitive, affective, behavioral, and metacognitive outcomes, with cognitive outcomes receiving the most extensive research attention.

Keywords: Generative AI, Project-Based Learning, Pedagogical Scaffolding, Learning Outcomes, Systematic Literature Review

Introduction

The rapid development of large language models and multimodal generative technologies has positioned generative artificial intelligence (GenAI) as an increasingly influential technological force in education. GenAI can generate diverse forms of content in response to natural language prompts, including explanations, summaries, questions, text drafts, code, images, and other multimodal outputs (Yusuf et al., 2024). Its expanding generative and interactive capabilities have attracted widespread attention to its potential applications in educational contexts. In teaching and learning, GenAI has been used for various purposes, including developing instructional materials, explaining complex concepts, supporting writing, solving problems, generating creative ideas, designing exercises, and providing immediate feedback (Kasneci et al., 2023). These applications not only broaden the ways in which learners access educational resources but also offer more flexible and timely learning support. They further provide educators with new technological opportunities to improve instructional design and adapt their teaching strategies.

Project-based learning (PjBL) is a student-centered pedagogical approach that emphasizes sustained inquiry, knowledge application, teamwork, and the development of tangible outcomes around problems or challenges situated in authentic contexts (Boardman et al., 2024). Unlike traditional instructional approaches that primarily emphasize knowledge transmission, PjBL requires students to engage actively in relatively open-ended and complex tasks. Throughout the process, students are expected to plan projects, formulate questions, collect and analyze information, implement solutions, and reflect on both their learning processes and project outcomes. Such experiences can promote knowledge construction, critical thinking, problem-solving, and other important competencies (Al-Kamzari & Alias, 2025). However, the open-ended, complex, and sustained nature of PjBL also places considerable demands on learners. Students may encounter difficulties in defining project goals, breaking down tasks, selecting relevant information, choosing appropriate strategies, collaborating with team members, and managing their learning progress (Miao et al., 2024; Tamaki et al., 2025). Accordingly, providing appropriate pedagogical support is an important consideration in the effective implementation of PjBL.

Against this background, GenAI offers new possibilities for providing pedagogical support in PjBL. Through natural language interaction, content generation, and immediate feedback, GenAI can provide students with various forms of assistance throughout project development, such as generating project ideas, clarifying task requirements, explaining complex concepts, and offering operational guidance (Y. Chen et al., 2026). These capabilities enable GenAI to move beyond the role of a simple information retrieval or content generation tool and become more actively involved in students' project-based learning processes, potentially functioning as pedagogical scaffolding across different task contexts (Zhang et al., 2026). Meanwhile, PjBL is characterized by phased and dynamic development, with students facing different learning tasks and support needs during the planning, inquiry, execution, and reflection phases (Cao, 2024). It is therefore necessary to examine further how GenAI provides differentiated support as projects progress and how such support relates to students' learning activities and outcomes.

Despite the growing body of research on the applications of GenAI in education, existing reviews have primarily examined its educational applications, instructional practices, and

potential challenges from a broad perspective. For example, Yusuf et al. (2024) conducted a systematic mapping review of GenAI in education and research, summarizing major application themes, developmental trends, and gaps in the existing literature. Qian (2025), focusing on the pedagogical applications of GenAI in higher education, highlighted its potential to promote creative thinking, critical thinking, and learner autonomy, while also identifying concerns regarding students' overreliance on AI and the outsourcing of cognitive processes. Meanwhile, Z. Chen et al. (2026) conducted a systematic review and three-level meta-analysis of GenAI-supported problem-based and project-based learning, synthesizing 22 controlled studies and 66 effect sizes. Their findings indicated positive effects of GenAI on learning achievement and skill performance. Although this review synthesizes evidence from problem-based and project-based learning and examines the effects of GenAI-supported learning, it does not specifically focus on PjBL or organize the evidence around the scaffolding functions of GenAI within this pedagogical approach. Therefore, these reviews have highlighted the potential of GenAI in education from different perspectives and provided important foundations for understanding its pedagogical value.

Project-based learning has also generated a substantial body of research, with existing literature primarily focusing on instructional design, implementation processes, learning activities, and student learning outcomes. For example, Al-Kamzari and Alias (2025) conducted a systematic review of project-based learning in secondary school physics education, examining its theoretical foundations, essential components, design principles, and implementation strategies, while also synthesizing the student learning outcomes reported in the reviewed studies. Hinostroza et al. (2025) further examined the phases and learning activities involved in integrating digital technologies into project-based learning. These reviews provide valuable insights into PjBL design and technology integration. However, existing reviews have yet to adequately address the scaffolding functions of generative artificial intelligence in project-based learning, particularly the forms of support it provides, the stages at which it is deployed, and its effects on student learning outcomes.

To address this need, this study conducts a systematic literature review of GenAI as pedagogical scaffolding specifically in PjBL. First, it synthesizes the forms of support reported in the included studies into six types of pedagogical scaffolding, offering a function-oriented account of GenAI use in PjBL. Second, it examines how GenAI supports students across the four phases of PjBL: planning, inquiry, execution, and reflection. Third, it explores the relationships between GenAI scaffolding and five domains of student learning outcomes: academic achievement, cognitive, metacognitive, affective, and behavioral. In doing so, this review systematically synthesises the existing research evidence on GenAI in Project-Based Learning from the perspective of pedagogical scaffolding, deepening our understanding of its instructional functions, practical value and educational potential, and providing a significant reference for future research into the theoretical development and pedagogical practice of GenAI-supported PjBL. Accordingly, this review is guided by the following three research questions:

1. What types of pedagogical scaffolding are provided by generative AI in project-based learning?
2. How does generative AI support students across the different phases of project-based learning, including planning, inquiry, execution, and reflection?

3. What relationships are reported between generative AI scaffolding and student learning outcomes in project-based learning?

Methodology

Systematic Search Procedures

This study adopted a systematic literature review (SLR) to examine research on the use of generative artificial intelligence as pedagogical scaffolding in project-based learning. To ensure the rigor and transparency of the literature search and selection processes, the review followed the PRISMA 2020 guidelines (Page et al., 2021). The study selection process consisted of four stages: identification, screening, eligibility assessment, and inclusion. The detailed procedure is illustrated in Figure 1.

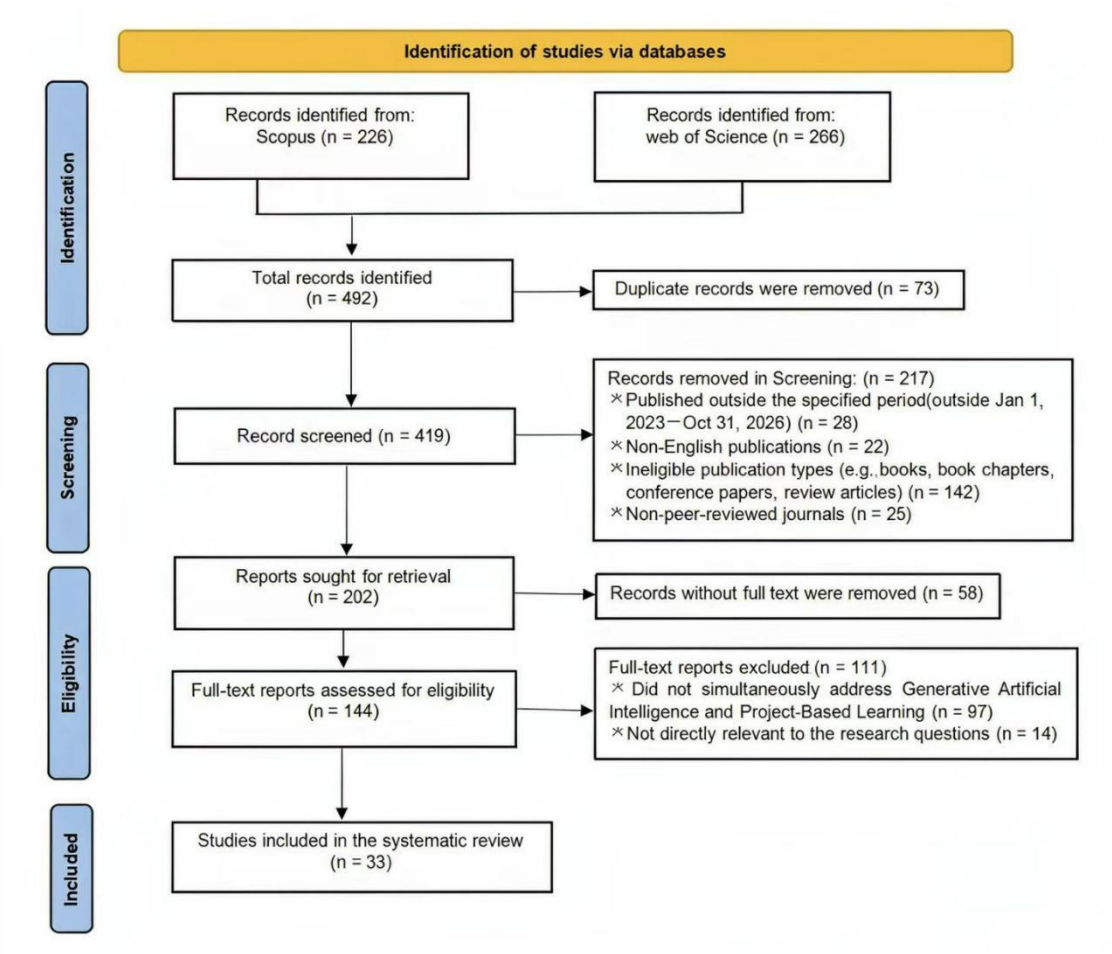

Figure 1. Adapted PRISMA systematic selection process

Study Identification and Selection Phase

This study searched two major academic databases, Scopus and Web of Science (WoS), to identify research related to GenAI and project-based learning. The publication period was restricted to January 1, 2023, through October 31, 2026. Given the differences in search syntax, field settings, and indexing rules across databases, the search strategies were adapted to the respective requirements of each database to ensure their applicability and consistency. Specifically, the TITLE-ABS-KEY field was used to search Scopus, whereas the Topic (TS) field was used for Web of Science.

This review focused on the application of GenAI in project-based learning contexts, with particular attention to how GenAI is integrated into the project learning process and provides pedagogical support for students. To ensure the relevance of the included studies, only educational research explicitly combining GenAI with project-based learning was considered. In other words, the application of GenAI had to be situated within a clearly identifiable project-based teaching or learning context and involve support for students' project-related learning activities. Studies examining GenAI applications in general educational contexts without involving PjBL, as well as studies combining PjBL with other learning approaches, such as problem-based learning, were excluded. Regarding the type of technology, this review included only studies focusing on generative artificial intelligence (GenAI). Studies involving only conventional artificial intelligence or other non-generative technologies, as well as those combining GenAI with other types of AI technologies, were excluded. These criteria were established to ensure consistency in the learning contexts and technology types represented in the included studies, thereby enabling a more accurate identification and analysis of the specific applications and pedagogical support functions of GenAI in PjBL.

Based on the research objectives and search strategy, the following core search expression was developed: ("artificial intelligence" OR "generative AI" OR "Chat GPT" OR "AI chatbot" OR "intelligent tutoring system") AND ("project-based learning" OR "project based learning" OR "project-based instruction" OR "project-based teaching").

The search covered English-language, peer-reviewed publications published between January 1, 2023, and October 31, 2026. The initial searches retrieved 492 records, including 226 from Scopus and 266 from Web of Science. The search results were subsequently deduplicated, and 73 duplicate records were identified and removed, leaving 419 unique records for subsequent screening.

During the screening stage, the 419 unique records were initially screened for relevance according to the predefined inclusion and exclusion criteria. Preliminary screening criteria focused on publication type, publication period, language, and peer-review status. Specifically, studies were required to meet all three of the following conditions: (1) be published in English; (2) have been published between January 1st, 2023, and October 31st, 2026; and (3) be peer-reviewed journal articles. Accordingly, books, book chapters, conference papers, and review articles were excluded as ineligible publication types. The inclusion and exclusion criteria are presented in Table 1.

Table 1
Inclusion and Exclusion Criteria

Inclusion criteria	**Exclusion criteria**
Articles published in English	Articles not published in English
Published between January 1st, 2023 and October 31st, 2026	Articles published outside the specified period
Peer-reviewed journal articles	Non-peer-reviewed publications
Original journal articles	Books, book chapters, conference papers, and review articles

A total of 217 records were excluded based on these criteria. Of these, 25 were excluded because they were not peer-reviewed, 28 because they fell outside the specified publication

period, 22 because they were published in languages other than English, and 142 because they did not meet the publication-type criteria. Following this preliminary screening, 202 records remained for full-text retrieval and eligibility assessment. To enhance the rigor and consistency of the screening process, two reviewers independently screened the records and made judgments based on the predefined criteria. Any disagreements were initially resolved through discussion and consultation between the two reviewers.

Study Eligibility and Inclusion Phase

During the full-text retrieval and eligibility assessment phase, the 202 records retained after preliminary screening were sought for retrieval and full-text examination. However, 58 reports could not be obtained and were therefore excluded from further eligibility assessment. Full texts were successfully retrieved for the remaining 144 reports, which were subsequently assessed to determine whether they met the predefined inclusion criteria. Specifically, studies were required to satisfy both of the following conditions: (1) explicitly examine the application of generative artificial intelligence (GenAI) in project-based learning (PjBL); and (2) address at least one of the research questions of this review, namely, the types of GenAI pedagogical scaffolding, its forms of support across the planning, inquiry, execution, and reflection phases of PjBL, or its relationships with student learning outcomes.

Following the full-text eligibility assessment, 111 studies were excluded because they did not meet the predefined inclusion criteria. Specifically, 97 studies did not simultaneously address GenAI and PjBL, while 14 studies were not directly relevant to the research questions. Ultimately, 33 studies met all the eligibility criteria and were included in this systematic literature review. To ensure the rigor and consistency of the full-text retrieval and eligibility assessment processes, two researchers independently conducted the full-text retrieval and assessment. Any disagreements regarding study eligibility were resolved through discussion between the two researchers, and the final selection decisions were made after consensus was reached.

Results

Types and Functions of Generative AI Scaffolding in Project-Based Learning

Through a systematic analysis and synthesis of the included studies, this review identified six major types of pedagogical scaffolding provided by generative artificial intelligence (GenAI) in project-based learning (PjBL): conceptual, procedural, metacognitive, strategic, motivational, and collaborative scaffolding. These scaffolding types address different student needs in PjBL, including understanding knowledge, completing tasks, monitoring learning, selecting strategies, maintaining engagement, and engaging in collaboration. Accordingly, GenAI tools can serve multiple pedagogical functions through interactive mechanisms such as explanations, examples, questioning, feedback, and dialogue. The six types of scaffolding and their functions are presented in Table 2.

Table 2

Types and Functions of Generative AI Scaffolding in Project-Based Learning

Scaffolding Type	Scaffolding Function	GenAI-Supported Activities	Supporting Studies
Conceptual Scaffolding（n=26）	Supports students in understanding concepts, constructing knowledge, and clarifying complex issues	Explaining key concepts, providing examples, and helping students understand project topics	Dai et al. (2025) ; Al Labadi & Ly (2025) ; Wang et al. (2025) ; Mi, & Bin Jamaludin (2026) ; Darban (2024) ; Yi et al. (2025) ; Zhang et al. (2026) ; Duc (2026);Nguyen & Doan (2025) ; Smith (2025) ; Priyadarsini et al. (2026) ; Plessis (2025) ; Sadik (2025) : Tian et al. (2026)， Patarakin et al. (2025)， Al Labadi et al. (2026)， Perifanou & Economides (2025)， Zheng et al. (2024)， Bento et al. (2026)， Jingqian et al. (2024)， Jaramillo-Fierro et al. (2026)， Sinnari (2026)， Pernaa et al. (2025)， Liu et al. (2025)， Ge et al. (2026)， Farrell et al. (2026)
Procedural Scaffolding（n=19）	Guides students in completing tasks, understanding operational steps, and following project procedures	Providing step-by-step instructions, operational suggestions, and task-completion prompts	Dai et al. (2025) ; Al Labadi & Ly (2025) ; Wang et al. (2025) ; Mi, & Bin Jamaludin (2026) ; Darban (2024) ; Yi et al. (2025) ; Zhang et al. (2026) ; Duc (2026) ; Sadik (2025) ; Muengsan et al. (2025) ; Patarakin et al. (2025)， Bakshi (2026)， Al Labadi et al. (2026)， Perifanou and Economides (2025)， Zheng et al. (2024)， Bento et al. (2026)， Jingqian et al. (2024)， Pernaa et al. (2025)， Ge et al. (2026)
Metacognitive Scaffolding（n=10）	Supports students in monitoring, evaluating, and regulating their own learning processes	Asking reflective questions, guiding self-assessment, and providing prompts for learning regulation	Dai et al. (2025) ; Sajadi et al.（2024）、Mi, & Bin Jamaludin (2026) ; Kahaleh et al. (2026) ; Yi et al. (2025) ; Zhang et al. (2026) ; Duc (2026) ; Karabalin et al. (2026) ; Indriati et al. (2026) ; Farrell et al. (2026)
Strategic Scaffolding（n=18）	Helps students select strategies, develop solutions, and address complex problems	Suggesting alternative solutions, comparing strategies, and supporting decision-making	Dai et al. (2025) ; Wang et al. (2025) ; Mi, & Bin Jamaludin (2026) ; Darban (2024) ; Kahaleh et al. (2026) ; Yi et al. (2025) ; Zhang et al. (2026) ; Duc (2026);Nguyen & Doan (2025) ; Smith (2025) ; Plessis (2025) ; Karabalin et al. (2026) ; Sadik (2025) ; Indriati et al. (2026) ; Patarakin et al. (2025)， Perifanou and Economides (2025)， Zheng et al. (2024)， Bento et al. (2026)
Motivational Scaffolding（n=5）	Supports learning motivation, engagement, and task persistence	Providing encouraging feedback, reminders of learning goals, and supportive dialogue	Sajadi et al.（2024） ; Zhang et al. (2026) ; Duc (2026); Nguyen & Doan (2025) ; Priyadarsini et al. (2026) ;
Collaborative Scaffolding（n=11）	Promotes group communication, negotiation, and	Facilitating group brainstorming, encouraging the	Dai et al. (2025) ; Wang et al. (2025) ; Sajadi et al. (2024)、Mi, & Bin Jamaludin (2026) ; Darban (2024) ; Kahaleh et al. (2026) ; Duc

Scaffolding Type	Scaffolding Function	GenAI-Supported Activities	Supporting Studies
	knowledge construction	co-exchange of perspectives, and group coordination	(2026); Nguyen & Doan (2025) ; Indriati et al. (2026) ; Perifanou and Economides (2025), Ge et al. (2026)

Conceptual scaffolding primarily supports students' understanding of key concepts, disciplinary knowledge, and complex problems, thereby facilitating knowledge construction and integration throughout the PjBL process. The synthesis revealed that conceptual scaffolding was the most frequently reported type, appearing in 26 studies. This indicates that conceptual understanding and knowledge construction constitute major areas of research interest in the application of GenAI to PjBL. Specifically, GenAI provides conceptual support by explaining abstract concepts, clarifying complex content, offering concrete examples, and responding to students' questions with additional background information (Dai et al., 2025; Al Labadi & Ly, 2025; Wang et al., 2025; Zhang et al., 2026; Duc, 2026). This form of scaffolding primarily addresses the cognitive difficulties students encounter when developing conceptual understanding and constructing meaning.

In addition to conceptual scaffolding, procedural and strategic scaffolding were also prominent forms of pedagogical support in the existing literature, appearing in 19 and 18 studies, respectively. These findings reflect considerable research attention to the role of GenAI in supporting project task implementation and complex problem-solving. Procedural scaffolding primarily concerns helping students translate complex or abstract project requirements into clear, specific, and actionable steps. Previous studies have shown that GenAI can provide step-by-step instructions, operational suggestions, task-completion prompts, and technical assistance, thereby helping students establish clear pathways for task execution and address procedural difficulties encountered during project implementation (Darban, 2024; Yi et al., 2025; Sadik, 2025; Bento et al., 2026). In contrast, strategic scaffolding places greater emphasis on supporting students in selecting solutions, comparing strategies, analyzing problems, and making decisions in complex project tasks. It enables students to explore alternative approaches and optimize their courses of action (Smith, 2025; Plessis, 2025; Sadik, 2025; Indriati et al., 2026). For example, Karabalin et al. (2026) described how GenAI provided multiple visual design options and supported rapid iteration, enabling students to explore and compare different design alternatives.

By comparison, collaborative, metacognitive, and motivational scaffolding received relatively less research attention, appearing in 11, 10, and 5 studies, respectively. These three types further extend the scope of GenAI-supported pedagogical functions in PjBL, reflecting its potential to facilitate teamwork, regulate learning processes, and sustain learning motivation. Collaborative scaffolding primarily concerns communication and cooperation among project group members, as well as the co-construction of knowledge. Existing studies indicate that GenAI can support collaborative learning activities by facilitating group brainstorming, providing shared discussion materials, encouraging the exchange of different perspectives, and assisting with team coordination (Darban, 2024; Kahaleh et al., 2026; Perifanou & Economides, 2025; Mi & Bin Jamaludin, 2026).

Metacognitive scaffolding, in turn, focuses on students' monitoring, evaluation, and regulation of their own learning processes. Related studies have shown that GenAI can support students in reviewing their learning progress and making appropriate adjustments by posing reflective questions, guiding self-assessment, prompting students to verify AI-generated content, and providing suggestions for modifying learning strategies (Sajadi et al., 2024; Kahaleh et al., 2026; Karabalin et al., 2026; Farrell et al., 2026). Among the six scaffolding types, motivational scaffolding was the least frequently reported, appearing in only five studies. This type of scaffolding focuses on students' learning motivation, willingness to participate, confidence, and persistence throughout project-based learning. Existing research suggests that GenAI can provide motivational support by offering positive feedback, encouraging prompts, and emotional support, thereby helping students cope with challenges and sustain their engagement in project activities (Sajadi et al., 2024; Zhang et al., 2026; Duc, 2026; Nguyen & Doan, 2025).

Generative AI Scaffolding Across Different Phases of Project-Based Learning

The synthesis of the included studies indicates that GenAI scaffolding operates across four phases of project-based learning: planning, inquiry, execution, and reflection. Its support mechanisms vary according to the learning tasks and requirements associated with each phase. As presented in Table 3, GenAI primarily provides phased pedagogical support through goal clarification and task decomposition, question prompting and information exploration, step-by-step guidance and iterative feedback, as well as reflective questioning and self-assessment. Regarding the distribution of research, the execution phase was examined in the largest number of studies (n = 29), followed by the planning and inquiry phases (both n = 20), while the reflection phase received comparatively less attention (n = 14). This distribution indicates that existing research has placed greater emphasis on the role of GenAI in supporting project implementation, while also revealing its differentiated pedagogical functions across the various phases of project-based learning.

Table 3
Generative AI Scaffolding Mechanisms Across the Phases of Project-Based Learning

PjBL Phase	Supported Learning Activities	GenAI Scaffolding Mechanism	SupportingStudies
Planning（n=20）	Clarifying project goals, generating project topics and ideas, and developing project plans and schedules	Idea generation, goal clarification, and task decomposition	Dai et al. (2025)； Mi, & Bin Jamaludin (2026)； Darban (2024)； Kahaleh et al. (2026)； Zhang et al. (2026)； Duc (2026);Nguyen & Doan (2025)； Plessis (2025)； Sadik (2025)； Tian et al. (2026)， Patarakin et al. (2025)， Bakshi (2026)， Al Labadi et al. (2026)， Perifanou and Economides (2025)， Zheng et al. (2024)， Bento et al. (2026)， Jingqian et al. (2024)， Sinnari (2026)， Liu et al. (2025)， Farrell et al. (2026)

PjBL Phase	Supported Learning Activities	GenAI Scaffolding Mechanism	SupportingStudies
Inquiry (n=20)	Formulating research questions, exploring information, developing hypotheses, and analyzing and synthesizing evidence	Question prompting, information exploration, and knowledge clarification	Dai et al. (2025); Wang et al. (2025); Mi, & Bin Jamaludin (2026); Darban (2024); Yi et al. (2025); Zhang et al. (2026); Duc (2026);Nguyen & Doan (2025); Smith (2025); Plessis (2025); Sadik (2025); Indriati et al. (2026); Tian et al. (2026), Al Labadi et al. (2026), Perifanou and Economides (2025), Zheng et al. (2024), Bento et al. (2026), Jaramillo-Fierro et al. (2026), Ge et al. (2026), Farrell et al. (2026)
Execution (n=29)	Developing project products, addressing implementation problems, refining designs, and adjusting implementation strategies	Step-by-step guidance, iterative feedback, and problem-solving support	Dai et al. (2025); Al Labadi & Ly (2025); Wang et al. (2025); Mi, & Bin Jamaludin (2026); Darban (2024); Kahaleh et al. (2026); Yi et al. (2025); Zhang et al. (2026); Duc (2026);Nguyen & Doan (2025); Smith (2025); Priyadarsini et al. (2026); Karabalin et al. (2026); Sadik (2025); Muengsan et al. (2025); Indriati et al. (2026); Tian et al. (2026), Patarakin et al. (2025), Al Labadi et al. (2026), Perifanou and Economides (2025), Zheng et al. (2024), Bento et al. (2026), Jingqian et al. (2024), Jaramillo-Fierro et al. (2026), Sinnari (2026), Pernaa et al. (2025), Liu et al. (2025), Ge et al. (2026), Farrell et al. (2026)
Reflection (n=14)	Evaluating project outcomes, reflecting on learning processes, identifying shortcomings, and proposing improvements	Reflective questioning, self-assessment prompts, and feedback-based revision	Dai et al. (2025); Sajadi et al. (2024); Mi, & Bin Jamaludin (2026); Yi et al. (2025); Zhang et al. (2026); Duc (2026);Nguyen & Doan (2025); Smith (2025); Karabalin et al. (2026); Indriati et al. (2026); Perifanou and Economides (2025), Zheng et al. (2024), Bento et al. (2026), Liu et al. (2025)

During the planning phase, GenAI primarily supports students in generating project topics and alternative ideas, clarifying project goals, breaking down complex tasks, and developing schedules. These forms of assistance help students transform preliminary project ideas into plans with clearly defined objectives and implementation pathways (Plessis, 2025; Sadik, 2025; Darban, 2024; Zhang et al., 2026). For example, Perifanou and Economides (2025) described how students used iterative prompting to ask GenAI to generate project ideas and suggest initial steps, after which they reviewed and revised the suggestions. The scaffolding mechanisms in this phase can be summarized as “idea generation-task clarification-planning refinement.” Their central function is to help students establish project directions, organize task structures, and develop preliminary plans that can be translated into actionable steps.

During the inquiry phase, GenAI primarily supports students by generating inquiry questions, suggesting information-search directions, explaining relevant concepts, helping formulate hypotheses, and facilitating the analysis and integration of information. These functions assist students in conducting inquiry activities related to their project topics (Wang et al., 2025; Yi et al., 2025; Sadik, 2025; Indriati et al., 2026; Jaramillo-Fierro et al., 2026). For example, Duc (2026) reported that students used GenAI to clarify unfamiliar vocabulary, reinterpret complex texts, and develop arguments. They also drew on AI-generated guiding questions and comparisons of perspectives across different texts to deepen their understanding and analysis of inquiry-related content. The scaffolding mechanisms in this phase can be summarized as "problem analysis-information exploration-perspective analysis–knowledge integration." Their central function is to help students clarify inquiry directions, understand complex information, and integrate relevant knowledge.

During the execution phase, GenAI primarily provides step-by-step guidance, iterative feedback, and problem-solving support, helping students translate project plans into concrete actions and continuously improve their project outcomes throughout implementation. The findings indicate that the execution phase was the most frequently examined of the four PjBL phases, with 29 studies reporting relevant support mechanisms. Specifically, GenAI supports students' project-based practical activities by providing operational guidance, generating suggestions for task implementation, and offering recommendations for problem-solving and solution refinement (Darban, 2024; Yi et al., 2025; Karabalin et al., 2026; Muengsan et al., 2025; Pernaa et al., 2025). For example, Al Labadi and Ly (2025) reported that generative AI could assist students with programming, data cleaning and preprocessing, data visualization, data analysis and interpretation, and project report writing, thereby providing technical support for project implementation. The scaffolding mechanisms in this phase can be summarized as "task implementation-problem-solving-solution refinement." Their central function is to help students address difficulties encountered during project implementation and facilitate the completion of project outcomes.

Compared with the other three phases, the reflection phase received the least research attention (n = 14). Existing studies indicate that GenAI can guide students in reviewing task completion, evaluating existing project outcomes, and considering directions for future improvement by posing reflective questions about learning processes and project outcomes, providing evaluation prompts, and generating targeted improvement suggestions (Sajadi et al., 2024; Yi et al., 2025; Karabalin et al., 2026; Liu et al., 2025). For example, Indriati et al. (2026) incorporated reflection activities into a structured GenAI dialogue process. Students first articulated their project design decisions, after which GenAI used critical questioning to guide them in examining the rationale underlying those decisions. Students then reconsidered their original proposals in light of the project requirements and made revisions accordingly. The scaffolding mechanisms in this phase can be summarized as "process review-critical reflection-feedback-based revision." Their central function is to help students identify shortcomings in their learning processes and project outcomes and provide a basis for subsequent adjustment and improvement.

Relationships Between Generative AI Scaffolding and Learning Outcomes in Project-Based Learning

The synthesis of the included studies revealed that the relationships between GenAI scaffolding and student learning outcomes encompass multiple dimensions, covering five domains: academic achievement, cognitive outcomes, metacognitive outcomes, affective outcomes, and behavioral outcomes. As shown in Table 4, existing research has examined not only students' academic performance in GenAI-supported learning environments but also changes in conceptual understanding, higher-order thinking, self-regulation, learning motivation, and learning engagement. In terms of research distribution, cognitive outcomes were the most extensively investigated, followed by affective and behavioral outcomes, whereas relatively fewer studies examined metacognitive outcomes and academic achievement.

Table 4
Reported Student Learning Outcomes

Learning Outcome Domain	Specific Learning Outcomes	Reported Relationships with GenAI Scaffolding	Supporting Studies
Academic Achievement （n=6）	Academic performance, test scores, course grades and project assessment scores	Reported changes in academic performance, achievement scores, and project grades associated with GenAI scaffolding	Dai et al. (2025)；Yi et al. (2025)；Dinu (2025)， Liu et al. (2025)， Ge et al. (2026)， Farrell et al. (2026)
Cognitive Outcomes （n=22）	Conceptual understanding, critical thinking, problem-solving, creativity and knowledge application	Reported changes in knowledge understanding, higher-order thinking, and problem-solving abilities	Dai et al. (2025)；Al Labadi & Ly (2025)；Darban (2024)；Kahaleh et al. (2026)；Yi et al. (2025)；Zhang et al. (2026)；Duc (2026);Smith (2025)；Tian et al. (2026)， Patarakin et al. (2025)， Bakshi (2026)， Al Labadi et al. (2026)， Perifanou and Economides (2025）， Bento et al. (2026)， Zheng et al. (2024)， Jaramillo-Fierro et al. (2026)， Sinnari (2026)， Liu et al. (2025)， Ge et al. (2026)Karabalin et al. (2026)；Sadik (2025)；Indriati et al. (2026)
Metacognitive Outcomes （n=7）	self-monitoring, reflective thinking and self-evaluation	Reported changes in students' ability to monitor, regulate, and reflect on their learning	Yi et al. (2025)；Nguyen & Doan (2025)；；Karabalin et al. (2026)；Indriati et al. (2026)；Bakshi (2026)， Zheng et al. (2024)， Liu et al. (2025)
Affective Outcomes （n=16）	Learning motivation, self-efficacy, confidence and learning satisfaction	Reported changes in motivation, confidence, self-efficacy, and satisfaction	Wang et al. (2025)；Yi et al. (2025)；Duc (2026)；Nguyen & Doan (2025)；Priyadarsini et al. (2026)；Karabalin et al. (2026)；Sadik (2025)；Indriati et al. (2026)；Bakshi (2026)， Zheng et al. (2024)， Bento et al. (2026)， Jaramillo-Fierro et al. (2026)， Dinu (2025)， Sinnari (2026)， Liu et al. (2025)， Ge et al. (2026)

Learning Outcome Domain	Specific Learning Outcomes	Reported Relationships with GenAI Scaffolding	Supporting Studies
Behavioral Outcomes （n=12）	Learning engagement, participation, task persistence and task completion	Reported changes in behavioral engagement, participation, persistence, and task completion	Dai et al. (2025)；Wang et al. (2025)；Kahaleh et al. (2026)；Yi et al. (2025)；Duc (2026)；Nguyen & Doan (2025)；Priyadarsini et al. (2026)；Sadik (2025)；Indriati et al. (2026)；Bakshi (2026)，Ge et al. (2026)，Farrell et al. (2026)

represented learning outcome domain among the included studies. The reported findings primarily focused on two aspects. First, in terms of knowledge understanding and application, students reported that the explanations, examples, and contextualized feedback provided by GenAI helped clarify disciplinary concepts and apply relevant knowledge to project tasks. These findings included students' understanding of statistical concepts and data analysis, interpretation of complex texts, and comprehension of artistic composition and design requirements (Al Labadi & Ly, 2025; Duc, 2026; Liu et al., 2025). Second, at the higher-order cognitive level, existing studies reported improvements in critical thinking, as well as students' abilities to analyze problems, compare alternative solutions, examine the rationale behind design decisions, and develop creative ideas. These findings indicate relationships between GenAI scaffolding and cognitive evaluation, exploration of alternative solutions, and creative expression (Zheng et al., 2024; Bento et al., 2026; Zhang et al., 2026). Overall, the cognitive outcomes reported in the included studies encompassed multiple levels, ranging from knowledge understanding to higher-order thinking, suggesting that GenAI scaffolding is associated with various cognitive performances in PjBL.

Affective and behavioral outcomes also constituted important areas of interest in the included studies, appearing in 16 and 12 studies, respectively. Regarding affective outcomes, the findings primarily concerned three aspects: learning interest and motivation, task confidence and self-efficacy, and learning experiences and satisfaction. First, students generally expressed positive attitudes toward AI-supported project activities, reporting that these activities helped make tasks more engaging, stimulate interest in exploration, and sustain their motivation to participate in projects (Zheng et al., 2024; Duc, 2026; Priyadarsini et al., 2026). Second, some studies reported that after completing design or programming tasks with AI assistance, students developed more positive perceptions of their ability to complete projects, reflected in increased task confidence, a sense of ownership of their work, and self-efficacy (Zheng et al., 2024; Liu et al., 2025; Sadik, 2025). Finally, students generally evaluated their learning experiences with AI support positively. These evaluations included reduced perceptions of task difficulty, recognition of the value of tool-supported assistance, and higher levels of learning satisfaction (Dinu, 2025; Bento et al., 2026; Jaramillo-Fierro et al., 2026).

Regarding behavioral outcomes, 12 studies examined the relationships between GenAI scaffolding and students' participation in learning activities, sustained engagement, and task completion. First, at the level of activity participation, the studies documented positive patterns of student involvement in classroom interactions, group discussions, and collaborative tasks. These included students reporting a greater willingness to express their views, positive peer evaluations of participation in discussions, and higher rates of classroom

interaction (Duc, 2026; Indriati et al., 2026; Ge et al., 2026). Second, in terms of sustained engagement, some studies reported that students continued learning when encountering difficulties in understanding, maintained their involvement in project activities, and demonstrated higher levels of learning engagement under structured arrangements for AI use (Duc, 2026; Bakshi, 2026; Yi et al., 2025). Finally, with regard to task progression and completion, some studies reported higher rates of on-time assignment submission, as well as students' completion of programming tasks, digital products, and reflection activities (Ge et al., 2026; Sadik, 2025; Bakshi, 2026). Overall, these findings indicate positive behavioral patterns in AI-supported project-based learning contexts.

By comparison, metacognitive outcomes and academic achievement received relatively limited research attention, appearing in seven and six studies, respectively. Regarding metacognitive outcomes, students reported more proactive monitoring of their learning progress, identification of comprehension difficulties, and seeking of explanations to address those difficulties (Nguyen & Doan, 2025). Other studies documented reflective activities in which students examined the rationale behind their design decisions and evaluated their own performance and skill development (Indriati et al., 2026; Bakshi, 2026; Karabalin et al., 2026). In addition, students adjusted their questioning approaches, verified information, and revised their original judgments in response to AI feedback (Yi et al., 2025; Indriati et al., 2026).

Regarding academic achievement, six studies reported positive performance associated with GenAI-supported learning, using test scores, course grades, and project assessment scores as indicators. Ge et al. (2026) reported higher mean scores on unit tests in the GenAI-enhanced instructional group. Liu et al. (2025) found a positive correlation between the frequency of GenAI use and course grades, while Dai et al. (2025) observed that higher-performing students engaged more deeply with GenAI. In project assessment, students in GenAI-supported groups, or those who adopted appropriate strategies for using GenAI, obtained higher scores (Dinu, 2025; Yi et al., 2025). The use of GenAI for learning and proofreading was also associated with higher team report scores (Farrell et al., 2026). These findings indicate positive relationships between GenAI-supported learning and academic performance.

Discussion

Multidimensional Functions and Mechanisms of Generative AI Scaffolding in Project-Based Learning

The six types of pedagogical scaffolding identified in this review indicate that the role of GenAI in PjBL extends beyond explaining knowledge and generating content to encompass task implementation, strategy selection, learning regulation, and social interaction. This finding highlights the capacity of GenAI to participate in the project learning process through sustained dialogue and feedback, providing support for students as they address different learning needs and challenges. From the perspective of scaffolding theory, the central consideration is not simply how much assistance learners receive, but whether the support is appropriately aligned with their current learning needs and facilitates the gradual transfer of responsibility to the learner (van de Pol et al., 2010; Frey et al., 2023). However, the distribution of the six scaffolding types across the literature was uneven. Conceptual, procedural, and strategic scaffolding received relatively greater attention, whereas research on metacognitive, collaborative, and motivational scaffolding remained comparatively limited. This distribution suggests that current explorations of GenAI have focused more heavily on

knowledge understanding and task progression, while giving less attention to how students regulate their own learning, co-construct meaning, and sustain engagement. It should be emphasized that these frequencies reflect the research and reporting emphases of the included studies and should not be interpreted as indicators of the pedagogical value or relative effectiveness of different scaffolding types.

Notably, the relatively greater attention given to conceptual, procedural, and strategic scaffolding indicates that current research on GenAI-supported pedagogical scaffolding in PjBL has primarily focused on cognitive- and task-oriented functions, particularly knowledge understanding, task execution, and problem-solving. This research orientation is consistent with the complex and open-ended nature of project-based learning. PjBL requires students to integrate and apply disciplinary knowledge, respond to uncertainty, and continuously adjust their problem-solving approaches (Shenbagavalli, 2025). GenAI can support students in addressing these complex tasks through conceptual explanations, step-by-step guidance, and suggestions of alternative solutions, thereby reducing the cognitive demands associated with understanding knowledge and implementing project tasks (Gou & Ren, 2025). However, while such support offers practical convenience, it may also increase students' dependence on GenAI. When students become accustomed to directly accepting AI-generated explanations, operational steps, or solutions, cognitive activities that would otherwise require independent inquiry may be displaced by AI, potentially reducing opportunities for independent thinking, critical judgment, and knowledge construction (Unkelos-Shpigel et al., 2026). This concern is particularly relevant to PjBL, which emphasizes authentic problem-solving and learner agency. Greater efficiency in completing tasks does not necessarily translate into deeper learning. As Zhang and Ma (2023) and Novalia et al. (2025) have pointed out, producing project outcomes more quickly is insufficient to demonstrate substantive improvements in students' knowledge understanding, reasoning abilities, or learning independence. Therefore, the value of GenAI scaffolding should not be assessed solely in terms of task completion. Greater attention should be paid to whether such support encourages students to engage actively in key cognitive processes, including conceptual understanding, strategy evaluation, and problem-solving, and whether it can gradually develop their capacity to complete complex tasks independently.

Furthermore, metacognitive, motivational, and collaborative scaffolding broaden the understanding of GenAI's pedagogical support functions, indicating that its potential role extends beyond individual knowledge processing and task execution to encompass learners' self-regulation, sustained engagement, and social interaction. Metacognitive scaffolding, in particular, uses reflective questioning, self-assessment, and information verification to encourage students to evaluate the reliability of information, examine their own understanding, and adjust their learning strategies. However, this form of support does not necessarily lead to the development of self-regulated learning abilities. If students become overly dependent on GenAI's evaluations and suggestions, monitoring and reflection activities may become superficial and could even weaken their capacity for independent judgment (Ngoveni, 2026). Therefore, the value of metacognitive scaffolding lies not merely in providing opportunities for self-monitoring and reflective evaluation, but also in whether it encourages students to verify information actively, revise their judgments, and regulate their strategies independently. Future research should further examine whether students can maintain their

capacity for independent reflection and autonomous decision-making as AI support is gradually withdrawn.

Meanwhile, collaborative scaffolding extends GenAI-supported learning to team interaction and knowledge co-construction. Discussion materials, suggestions, and feedback generated by GenAI can provide resources for group communication. However, sharing resources does not necessarily improve the quality of collaboration. Its value depends on whether such support facilitates the exchange of perspectives, critical questioning, negotiation, and collective decision-making among group members. As Singer-Freeman et al. (2026) have indicated, the use of shared chat spaces can incorporate interactions among students, teachers, and GenAI into collective discussions, allowing AI-generated suggestions to be jointly examined and evaluated. Thus, the value of collaborative scaffolding lies not only in facilitating information sharing but also in supporting the collective construction of knowledge and maintaining shared responsibility for project-related decisions. Compared with the other scaffolding types, motivational scaffolding received the least attention in the included literature, indicating that the role of GenAI in supporting students' sustained engagement requires further investigation. Positive feedback and emotional support may help students cope with project-related difficulties and strengthen their confidence. Nevertheless, positive short-term experiences do not necessarily translate into sustained learning engagement over time (Yang, 2025; Atef, 2026). In particular, it is important to distinguish temporary satisfaction arising from the novelty of technology or the convenience of task completion from sustained learning motivation developed through knowledge understanding and competency growth. Therefore, the value of motivational scaffolding should not be measured solely by its ability to stimulate learning interest, but also by whether it enables students to remain engaged when facing setbacks and repeated revisions, while gradually developing the capacity to address challenges independently. Future research should further investigate its role in supporting long-term learning motivation and task persistence.

Stage-Sensitive Adaptation and Dynamic Support of Generative AI Scaffolding in Project-Based Learning

This study found that GenAI scaffolding extends across the four phases of project-based learning-planning, inquiry, execution, and reflection-and exhibits functional characteristics that correspond to the task demands of each phase. This indicates that the pedagogical role of GenAI in project-based learning is not confined to a single phase but can provide various forms of support throughout the project process. However, the levels of research attention devoted to these phases differ markedly. The execution phase has received the most attention, reflecting the current literature's greater emphasis on GenAI support for task implementation and the development of project outputs. By contrast, the reflection phase has received the least attention, suggesting that further investigation is needed into how students use GenAI to examine their learning processes, reflect on the rationale behind their decisions, and translate feedback into subsequent improvements. It is important to emphasize that these differences in the distribution of research attention reflect the current focus of the literature, rather than indicating that scaffolding is more effective in the execution phase.

During the planning phase, GenAI helps students determine project directions, clarify task requirements, and formulate preliminary implementation plans through idea generation, task clarification, and goal setting. Wei's (2026) study indicates that preliminary project plans generated by GenAI can provide students with a basis for discussion and comparison, while supporting the progressive refinement of project plans through ongoing examination and revision. However, the convenience of idea generation and task planning may also lead students to rely prematurely on the problem frameworks and solution pathways provided by AI. This is particularly concerning when students adopt AI-generated plans before adequately understanding the project context and the nature of the problem, potentially weakening the self-directed inquiry emphasized in project-based learning. Therefore, scaffolding during the planning phase should not focus solely on the efficiency of project idea generation. Rather, it should encourage students to examine the validity of the problem, compare alternative plans, and adjust their planning directions in response to actual needs.

During the inquiry phase, the instructional support provided by GenAI further highlights the distinction between information acquisition and knowledge judgment. Duc's (2026) study indicates that GenAI supports students in understanding complex information and broadening their lines of inquiry through textual explanations, guiding questions, and comparisons of perspectives. However, even when GenAI-generated explanations appear logical, their content is not necessarily accurate or reliable, nor can they replace students' critical examination of information sources and evidence (Han & Gutierez, 2026). If students rely solely on AI-generated responses to integrate information, inquiry activities may remain at the level of knowledge acquisition, without sufficiently engaging in in-depth evidence analysis and independent argumentation (Darwin, 2024). Therefore, scaffolding during the inquiry phase should focus not merely on facilitating information acquisition but also on encouraging students to treat AI-generated content as explanations that require verification. Through comparing multiple sources, checking evidence, and conducting critical analysis, students can develop their own judgments. The central value of such support lies in moving students from passively receiving information toward actively constructing knowledge, thereby positioning GenAI as a tool for deepening inquiry rather than as a source of answers that replaces independent thinking.

Notably, the execution phase has received the greatest attention in the included literature, reflecting the current emphasis on GenAI support for task implementation and the development of project outputs. This distribution may be associated with the relatively explicit operational demands and observable project outputs characteristic of this phase. The operational guidance, technical assistance, and iterative suggestions provided by GenAI can help students address implementation difficulties and advance complex tasks (Perifanou & Economides, 2025; Karabalin et al., 2026; Muengsan et al., 2025). However, completing project outputs does not necessarily mean that students have genuinely mastered the relevant knowledge and skills. When students directly adopt AI-generated code, analytical results, or solutions without understanding their underlying principles, supporting evidence, or conditions of applicability, technical assistance may reduce opportunities for them to analyze problems, test hypotheses, and validate solutions. Accordingly, a key concern during the execution phase is whether the iteration of project outputs is accompanied by the development of students' understanding and judgment (Kaloyanova, 2026). Instructional design should preserve opportunities for students to experiment, revise, and validate, while

encouraging them to explain the rationale for accepting or rejecting AI suggestions. Thus, the value of GenAI scaffolding during the execution phase should be evaluated not only in terms of task completion efficiency and output quality but also in terms of whether students can explain the rationale for revisions, validate solutions, and independently apply relevant knowledge and skills to similar or transfer tasks.

By contrast, the reflection phase has received the least attention in the existing literature. This finding indicates that further research is needed into how GenAI scaffolding supports students in reflecting on their learning processes, evaluating project outcomes, and pursuing continuous improvement. As Indrašienė et al. (2023) emphasized, deep reflection does not emerge spontaneously; it requires explicit and systematic instructional guidance to promote in-depth analysis and critical examination of learning experiences. However, the provision of reflective questions or feedback by GenAI does not necessarily mean that students engage in deep reflection. If students merely revise project outputs in response to AI suggestions without actively analyzing the underlying causes of problems and the rationale for their decisions, reflection may remain at the level of superficial revision and fail to generate a deeper understanding of the learning process (Zhai, 2024; Elzerman, 2025). Therefore, the key to the reflection phase lies not merely in obtaining suggestions for improvement but also in guiding students to examine their previous decisions, evaluate alternative approaches, and translate insights gained through reflection into improvements in subsequent learning and practice. Future research should further investigate whether GenAI-supported reflection can move beyond the revision of project outputs to promote the development of students' self-evaluation and continuous improvement capabilities.

Learning Outcomes and Developmental Challenges of Generative AI Scaffolding in Project-Based Learning

This study found that GenAI scaffolding was positively associated with students' academic achievement and cognitive, metacognitive, affective, and behavioral outcomes, indicating its potential to promote multiple aspects of student learning in project-based learning. However, the existing literature shows considerable variation in research focus. Cognitive, affective, and behavioral outcomes have received greater attention, whereas evidence concerning metacognitive outcomes and academic achievement remains relatively limited. It is important to note that the positive learning outcomes reported in these studies do not necessarily indicate that GenAI scaffolding has consistent and stable facilitative effects. Its actual effects should be interpreted cautiously, taking into account the learning tasks, modes of scaffolding use, and outcome measurement methods.

Cognitive outcomes represent the most extensively investigated area in the existing literature, suggesting that GenAI has potential to support knowledge comprehension, problem-solving, and the development of higher-order thinking. This aligns with the emphasis of project-based learning on knowledge application and complex problem-solving (Markula & Aksela, 2022). Through conceptual explanations, contextualized feedback, and comparisons of alternative solutions, GenAI can provide cognitive support to help students address complex learning tasks. However, the convenience of knowledge acquisition does not necessarily lead to deeper understanding and thinking. When students directly adopt AI-generated explanations or solutions without actively analyzing and verifying them, high-quality project outputs may mask insufficient cognitive engagement. As Cong-Lem and Thuy-Dung (2026) noted, GenAI

may create opportunities for higher-order thinking by reducing the burden of basic tasks, but it may also lead to cognitive offloading and superficial learning in the absence of appropriate guidance. Therefore, the value of cognitive scaffolding lies not only in helping students understand knowledge and complete tasks but also in its capacity to promote critical analysis and knowledge transfer. Future research should further distinguish between task performance with AI assistance and students' actual cognitive capabilities when AI support is withdrawn, thereby enabling a more accurate assessment of GenAI's contribution to deep cognitive learning.

Positive findings in the affective and behavioral domains suggest that GenAI may create favorable conditions for students' continued participation in project activities by reducing perceived task difficulty and providing timely feedback. As Sadik (2025) and Bakshi (2026) noted, timely access to explanations and feedback may alleviate uncertainty when students encounter difficulties, making them more willing to continue trying. However, positive affective experiences do not necessarily translate into sustained learning engagement, nor can they be directly equated with high-quality cognitive engagement. Martin and Borup (2022) pointed out that learning engagement encompasses behavioral, affective, and cognitive dimensions that are interrelated but distinct. Accordingly, students' satisfaction with AI tools, higher classroom participation rates, or task completion rates are insufficient to provide a comprehensive account of their actual learning engagement. It is particularly important to distinguish short-term positive experiences arising from the novelty of technology and operational convenience from sustained learning motivation developed through knowledge comprehension and capability development. Therefore, the value of GenAI's affective and behavioral support should not be evaluated solely on the basis of whether students are willing to use the tools or complete tasks on time. Greater attention should be given to whether such support enables students to remain actively engaged when facing difficulties, repeated revisions, and challenges in teamwork, and to sustain their participation in cognitively demanding learning activities.

Although research on metacognitive outcomes and academic achievement remains relatively limited, existing findings provide valuable insights into the potential roles of GenAI scaffolding. Regarding metacognition, some studies have reported positive student performance in self-monitoring, self-reflection, and evaluation (Nguyen & Doan, 2025; Karabalin et al., 2026). However, students' ability to adjust their learning behaviors in response to GenAI feedback does not necessarily indicate an improvement in their autonomous self-regulation capabilities. The key issue is whether students can independently identify problems, critically evaluate feedback, and adjust their learning strategies. Therefore, future research should further examine whether students can maintain their abilities to plan, monitor, and reflect autonomously as GenAI support is gradually withdrawn, in order to determine whether external support has genuinely been internalized as metacognitive capability. With regard to academic achievement, although some studies have reported higher test scores, course grades, and project ratings, these positive findings should still be interpreted with caution. The assessment indicators used across studies vary. Test scores primarily reflect students' mastery of specific knowledge and skills, whereas project ratings may be influenced by multiple factors, including the extent of GenAI assistance, teamwork, and assessment criteria (Dinu, 2025; Liu et al., 2025). Future research should further control for these influencing factors and combine controlled studies, delayed assessments, and knowledge-transfer tasks

to examine the actual contribution of GenAI scaffolding to academic achievement, as well as the durability and transferability of the associated learning gains.

Limitations and Conclusion

Although this review systematically examined the types of pedagogical scaffolding provided by GenAI in project-based learning, its support mechanisms across different phases, and their associations with student learning outcomes, several limitations should be acknowledged. First, this study adopted relatively strict inclusion criteria and focused exclusively on studies that explicitly addressed both GenAI and project-based learning. Consequently, relevant studies involving the combined use of GenAI and other AI technologies in PjBL may have been omitted, thereby limiting the coverage of the available evidence. Second, this review included only English-language, peer-reviewed journal articles published between 2023 and 2026. Other research outputs, including non-English publications, conference papers, and academic books, were not covered, potentially affecting the comprehensiveness of the literature and the diversity of research perspectives. Furthermore, the literature search was limited to two databases, Web of Science and Scopus, which may have resulted in the omission of relevant studies indexed in ERIC, IEEE Xplore, and other databases in the fields of education and technology, thereby limiting the comprehensiveness of the search. Future research should therefore broaden the scope of literature searches to incorporate evidence from different languages, publication types, and research contexts, and conduct searches across multiple databases to further investigate the mechanisms through which GenAI scaffolding operates and its effects on learning.

This review systematically examined studies published between 2023 and 2026 on the use of GenAI to provide pedagogical scaffolding in project-based learning, with a particular focus on the types of scaffolding, phase-specific support mechanisms, and their associations with student learning outcomes. First, the review identified six types of pedagogical scaffolding: conceptual, procedural, strategic, metacognitive, collaborative, and motivational. These findings indicate that the support provided by GenAI extends beyond knowledge comprehension and task implementation to encompass learning regulation, teamwork, and motivation maintenance. Future research should further investigate the synergistic effects of different scaffolding types and their alignment with students' learning needs, while exploring how to provide effective support without fostering excessive reliance on AI. Second, GenAI scaffolding extends across the four phases of project-based learning-planning, inquiry, execution, and reflection-and exhibits distinct characteristics of support at each phase. Future research should pay greater attention to scaffolding during the reflection phase to promote students' autonomous reflection and continued development. Finally, GenAI scaffolding was positively associated with academic achievement and cognitive, metacognitive, affective, and behavioral outcomes, highlighting its potential to promote multiple aspects of student learning. Future research should combine longitudinal studies, controlled experiments, and multidimensional assessments to further examine its actual contributions and long-term effects.

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